Hadron+jet production @ RHIC/NLO

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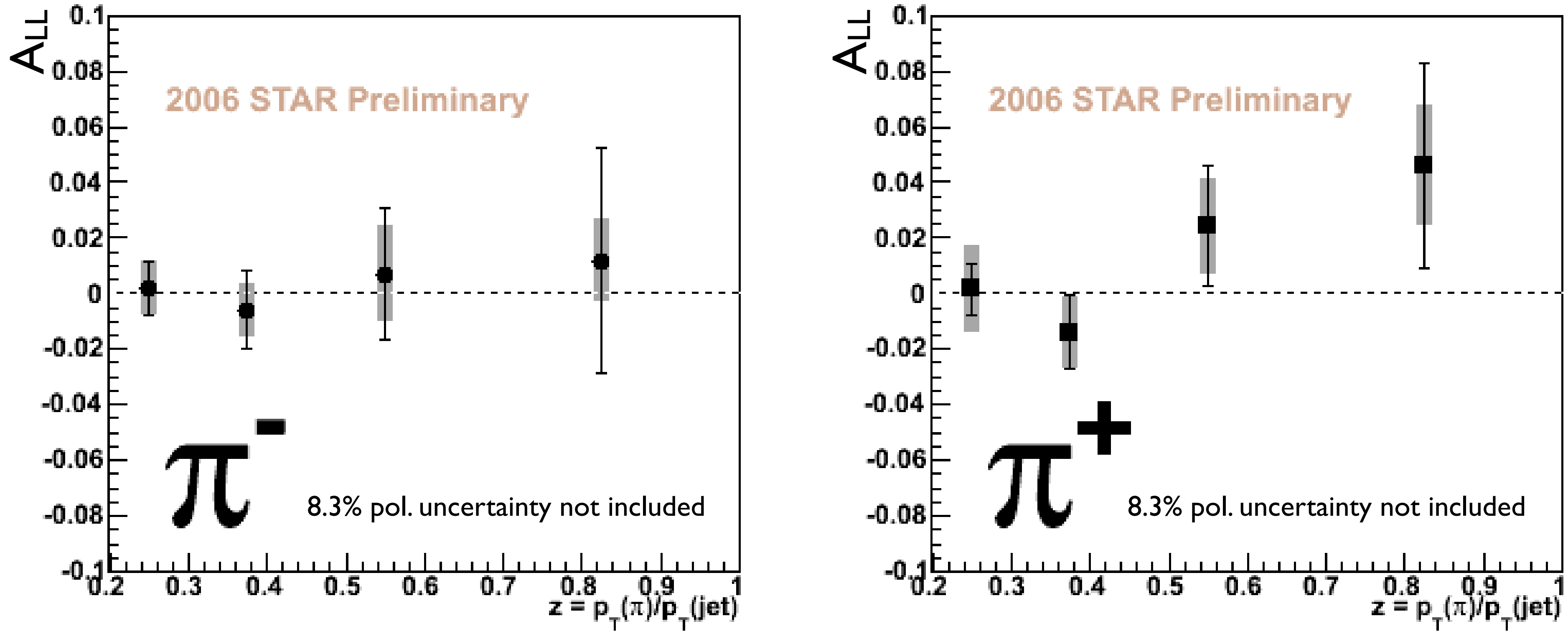
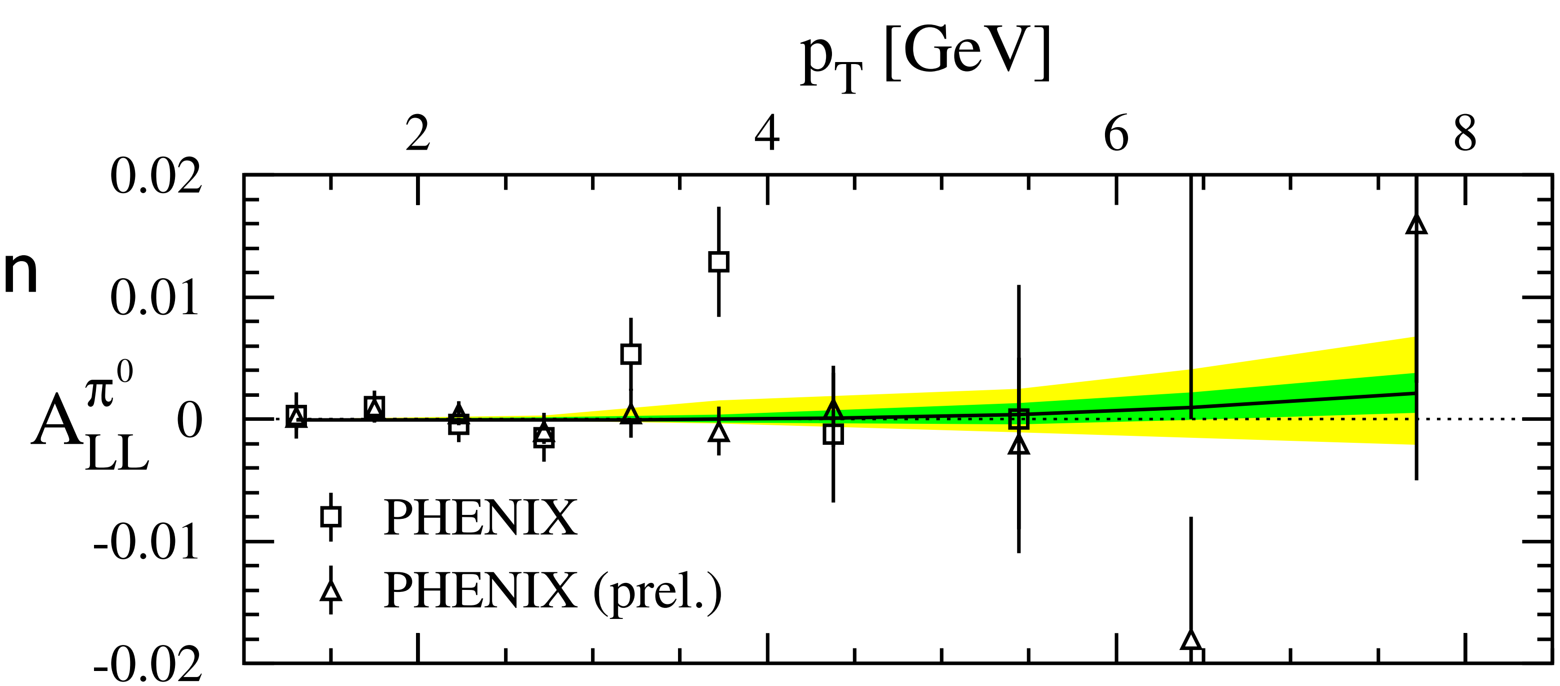
D de F. **arXiv:0904.4402 [hep-ph]**

New measurement at STAR : search for a pion opposite to a jet (back-to-back)

Pion+jet



Inclusive pion in global fit



- Important goal of spin program: ΔG

- DIS data hardly constrains the polarized gluon distribution

- pp observables are sensitive to ΔG

ΔG in global fits comes from jets and pion production at RHIC

Inclusive

- New pp observables can give complementary information

Prompt photons
Heavy quarks

- More exclusive observables

Dijets (Star)
Jet + pion (Star)
pion + photon (Phenix)

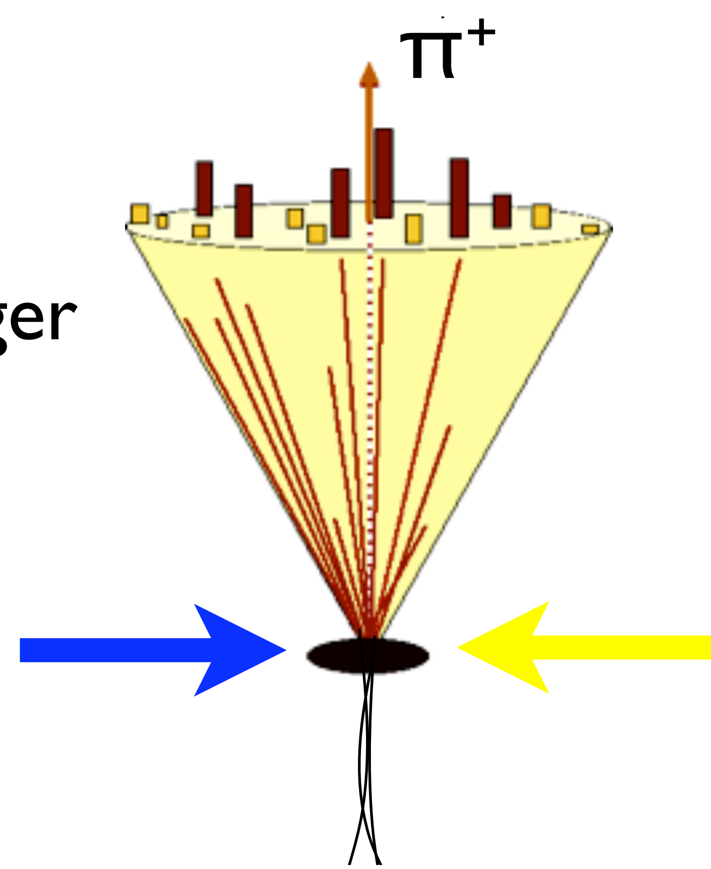
- More exclusive allows to perform a more detailed selection

Cuts to enhance some partonic channel
Plot data in term of other variables (enhance sensitivity)

- Charged pion production

Experimental reason: in inclusive measurements jet is used as a trigger for charged pions

jet trigger



A. Kocoloski

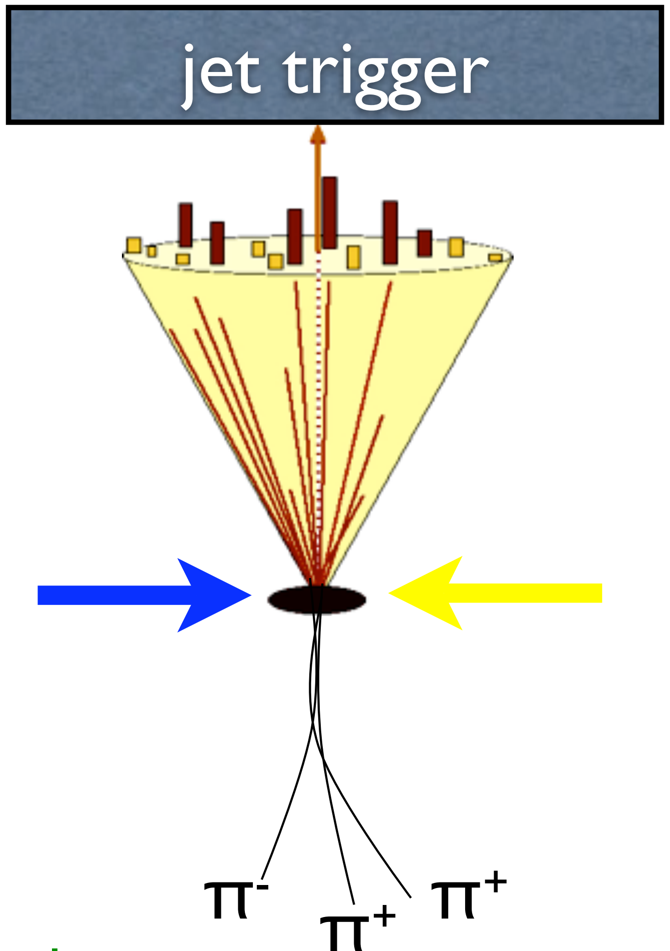
(2006) jet threshold at 8.3 GeV

Introduce bias towards small z (momentum fraction)

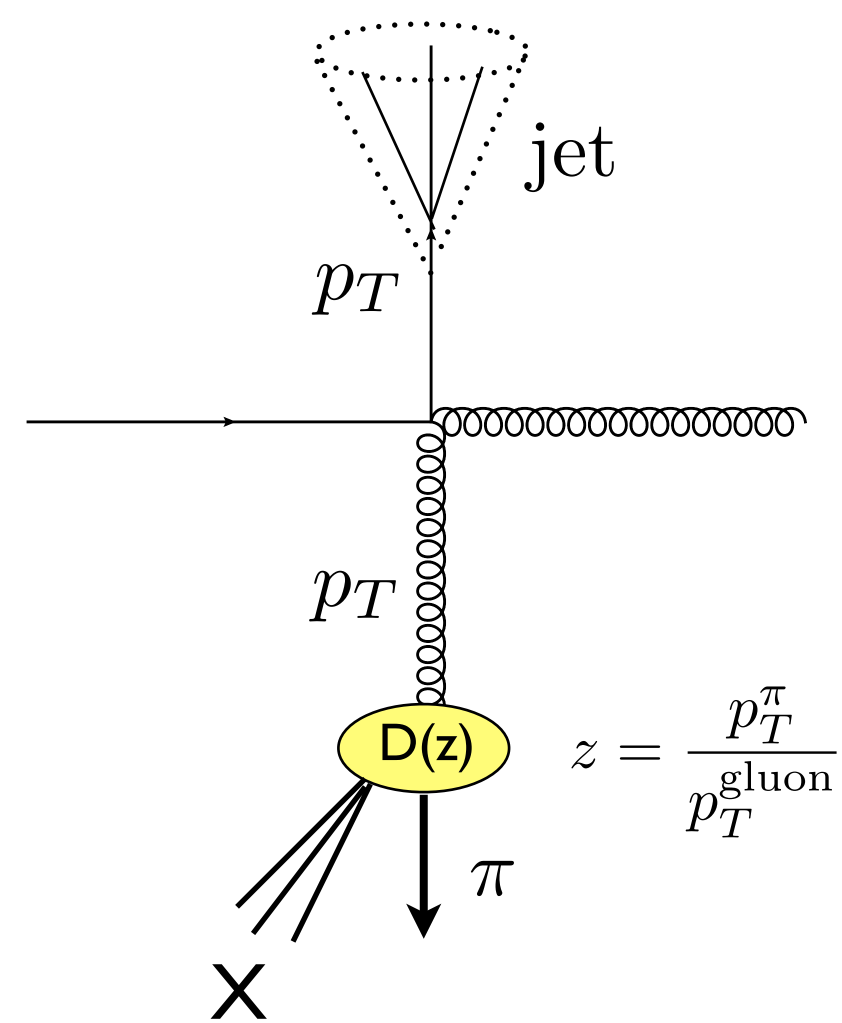
- Jet + charged pion production

  On the other hand, if jet is still used as trigger but pions observed on the opposite hemisphere

A. Kocoloski



Measure this one

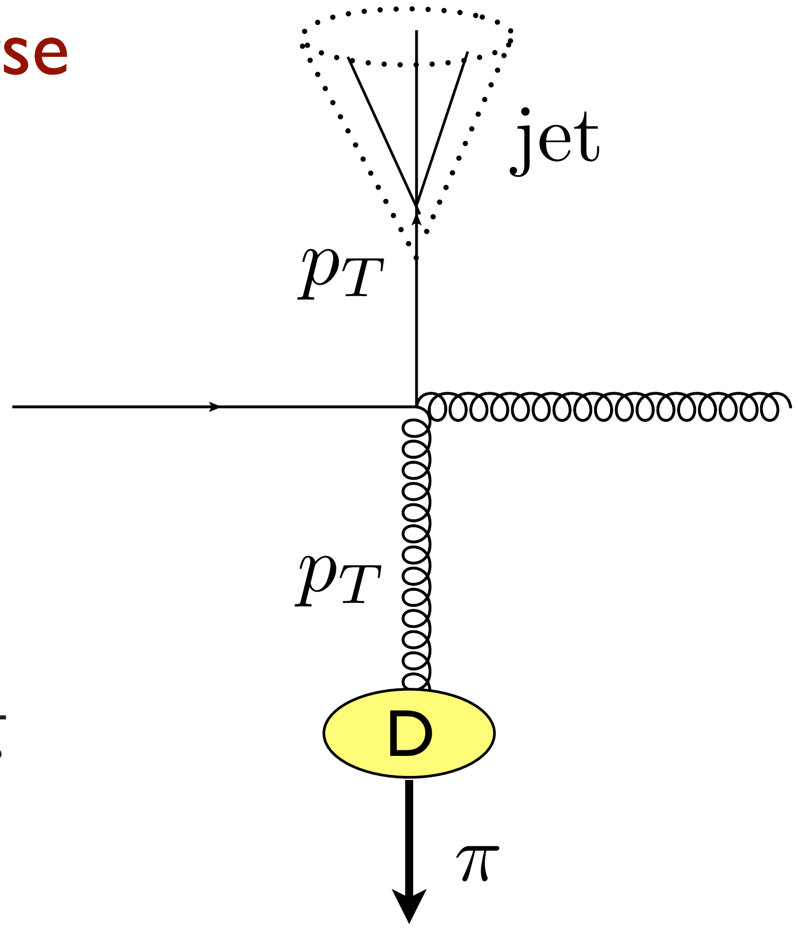


- Richer kinematics

  Plot in terms of $z \equiv \frac{p_T^\pi}{p_T^{\text{jet}}}$

- Has a parton-model interpretation

Considering LO kinematics and measuring transverse momentum and rapidity of jet and pion



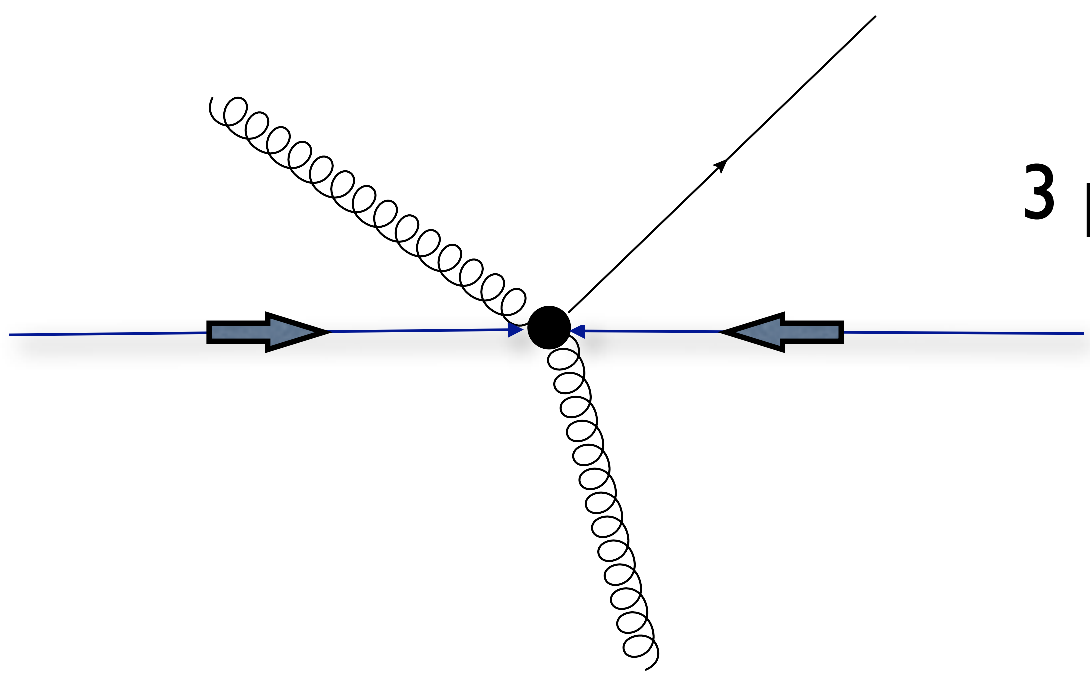
$$z \equiv \frac{p_T^h}{p_T^{jet}}$$

$$x_1 \equiv \left(p_T^{jet} \exp(\eta_{jet}) + p_T^{jet} \exp(\eta_h)\right) / \sqrt{s}$$

$$x_2 \equiv \left(p_T^{jet} \exp(-\eta_{jet}) + p_T^{jet} \exp(-\eta_h)\right) / \sqrt{s}$$

similar to dijets

Or course, naive relations only valid at LO (2 partons)!



3 partons

- LO calculations for pp collisions are only qualitative

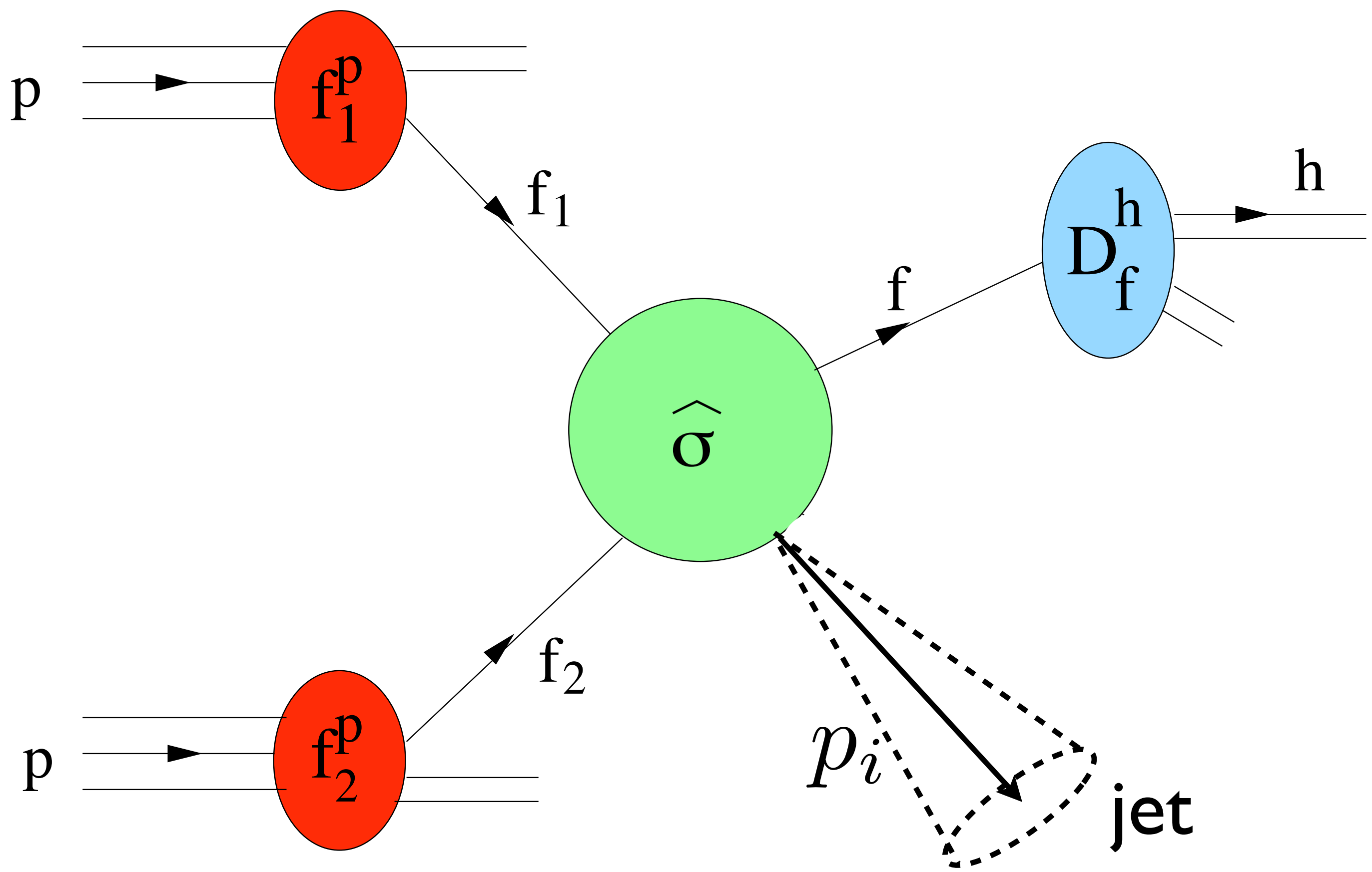
  Higher order corrections can be very sizeable
  Scale dependence at LO is very large
  More final state partons allow better matching of experimental conditions

- NLO corrections become essential for RHIC

  Naive relations for z, x : Do they change at NLO?
  Are the asymmetries affected by NLO corrections?
  Any cut can enhance the gluon contribution?

  Jet structure can be described only from NLO (trivial at LO)

TH description : factorization theorem



LO $\quad p_{jet} = p_1$

NLO $\quad p_{jet} = p_1 + p_2$

or $\quad p_{jet} = p_1$

$$d\sigma^{pp\to hX} = \sum_{f_1,f_2,f} \int dx_1\, dx_2\, dz\; f_1^p(x_1,\mu_{FI}^2)\; f_2^p(x_2,\mu_{FI}^2)$$
$$\times d\widehat{\sigma}^{f_1 f_2 \to f X'}(x_1\,p_1, x_2\,p_2, p_h/z, \mu_{FI}, \mu_{FF}, \mu_R)\; D_f^h(z,\mu_{FF}^2)\; S(p_i, jet)$$

Measurement function

In the polarised case $\vec{p}\vec{p} \Rightarrow\ \sigma,\ f_i^p \to \Delta\sigma,\ \Delta f_i^p$

- Computation of NLO corrections complicated

Many channels already at LO : several more at NLO

$$
\begin{array}{lll}
qq' \to qX & q\bar{q} \to gX & qq' \to gX \\
q\bar{q}' \to qX & qg \to qX & q\bar{q}' \to gX \\
q\bar{q} \to q'X & qg \to gX & qq \to gX \\
qq \to qX & gg \to gX & qg \to q'X \\
q\bar{q} \to qX & gg \to qX & qg \to \bar{q}'X \\
 & & qg \to \bar{q}X
\end{array}
$$

Real and virtual contributions both divergent : regularization needed

$2 \to 3$ $2 \to 2$ Dimensional regularization $n = 4 - 2\epsilon$

$$
d\hat{\sigma}_{ab\to cX'} \propto \int dPS_3 \; |M_{\text{tree}}^{ab->c+2\text{partons}}|^2 \; \mathcal{S}_3
$$

$$
+ \int dPS_2 \; |M_{1\text{loop}}^{ab->c+1\text{parton}}|^2 \; \mathcal{S}_2
$$

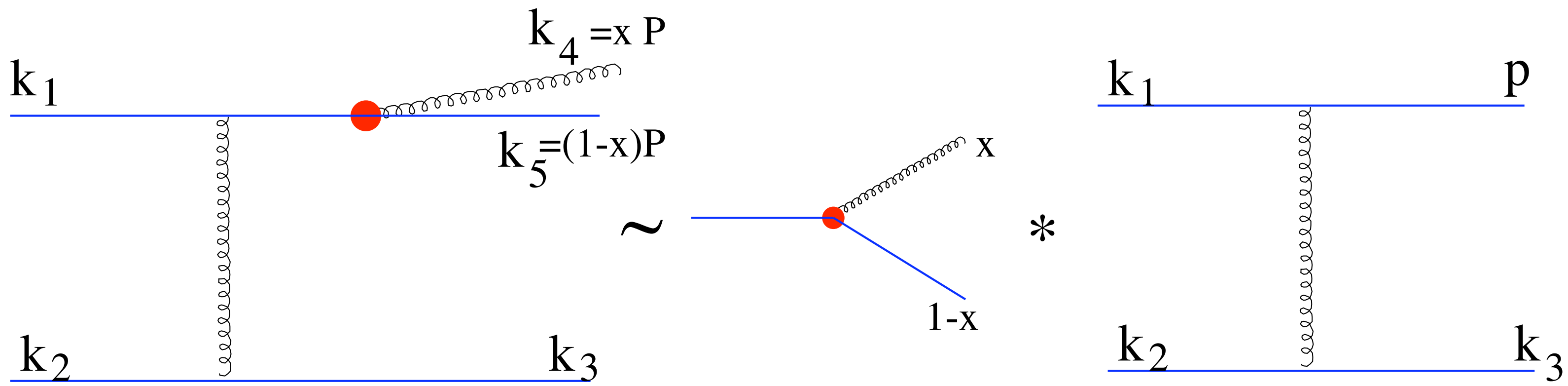
$$
+ \text{ factorization/renormalization terms}
$$

Phase space integrals for 3 particles complicated : analytic for inclusive observable, but more complicated for exclusive quantities (1 calculation for each observable)

- Try a more general numerical approach : how to deal with divergencies?

Identify origin of singular terms in real contribution: soft and collinear emission

- $qq \rightarrow qqg$ when $q \parallel g$ carring a fraction (1-x)/x of the 'parent' quark



- Use universal structure of infrared divergencies

$$\lim_{k_4 \cdot k_5 \to 0} |M_{\text{tree}}^{qq->qqg}|^2 \longrightarrow \frac{4\pi\mu^{2\epsilon}\alpha_s}{k_4 \cdot k_5} P_{gq}(x) \quad |M_{\text{tree}}^{qq->qq}|^2$$

- Add and subtract the (limit of) divergent contribution

$$\int dPS_3 \left(|M_{\text{tree}}^{qq->qqg}|^2 - \lim_{k_4 \cdot k_5 \to 0} |M_{\text{tree}}^{qq->qqg}|^2 \right) + \int dPS_3 \lim_{k_4 \cdot k_5 \to 0} |M_{\text{tree}}^{qq->qqg}|^2$$

Finite: compute numerically

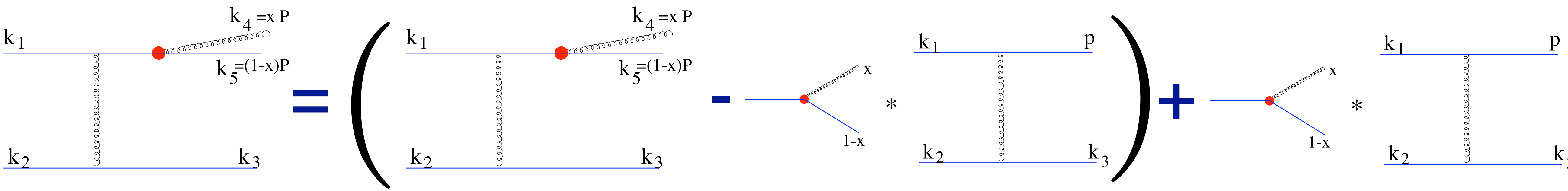
simpler and universal!

$$\sim \frac{1}{\epsilon} \int dx\, P_{gq}(x) \quad \left[|M_{\text{tree}}^{qq->qqg}|^2 \, dPS_2 \right]$$

Cancel with virtual contributions

Subtraction Method

infrared limit   infrared limit



finite = compute numerically

Free of any unphysical cutoff

divergent (simpler!)
cancel with virtual

Phase Space Integration with vegas :

- generate full phase space and x's / z
- compute pdfs/ffs at corresponding x/z
- compute weight for the event (matrix element +subtraction)
- bin the results according to observable : cross-section

Full access to final and initial state kinematics :
compute any infrared-safe observable

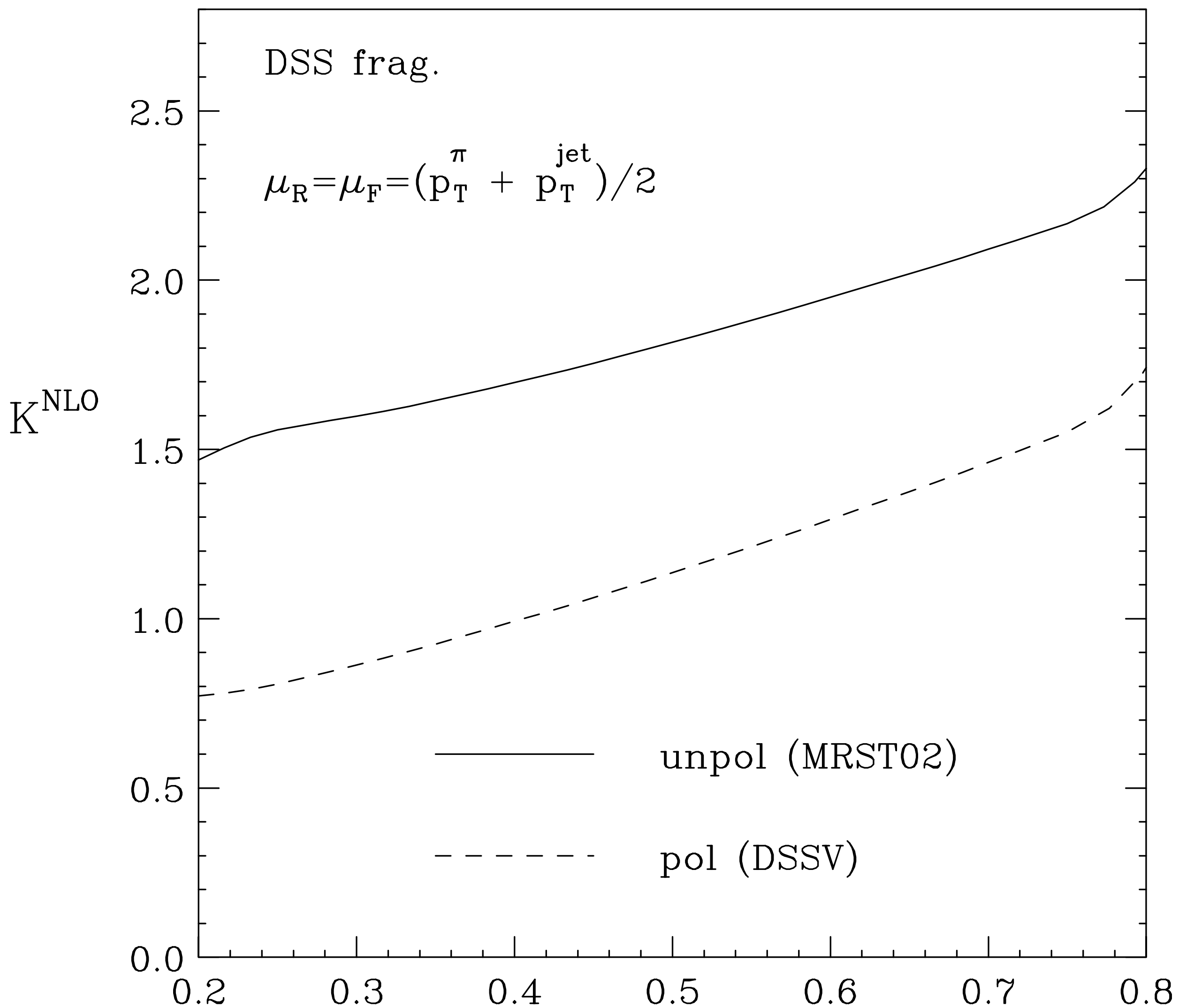
- Exclusive to implement experimental cuts ✓
- "Ready/Available" for Mellin implementation ✓
- Full NLO in line with other observables already in fit ✓

NLO effect

- NLO $\pi^+ + \text{jet}$

$\sqrt{S} = 200\,\text{GeV}$

$$K = \frac{\sigma^{NLO}}{\sigma^{LO}}$$



$$z \equiv \frac{p_T^{\pi}}{p_T^{\text{jet}}}$$

$$\text{jet cone } R = 0.7$$

$$25\,\text{GeV} > p_T^{\text{jet}} > 10\,\text{GeV}$$

$$p_T^{\pi} > 2\,\text{GeV}$$

$$|\eta| < 1$$

$$\Delta\phi \equiv \left|\phi^{\pi} - \phi^{jet}\right| > 2$$

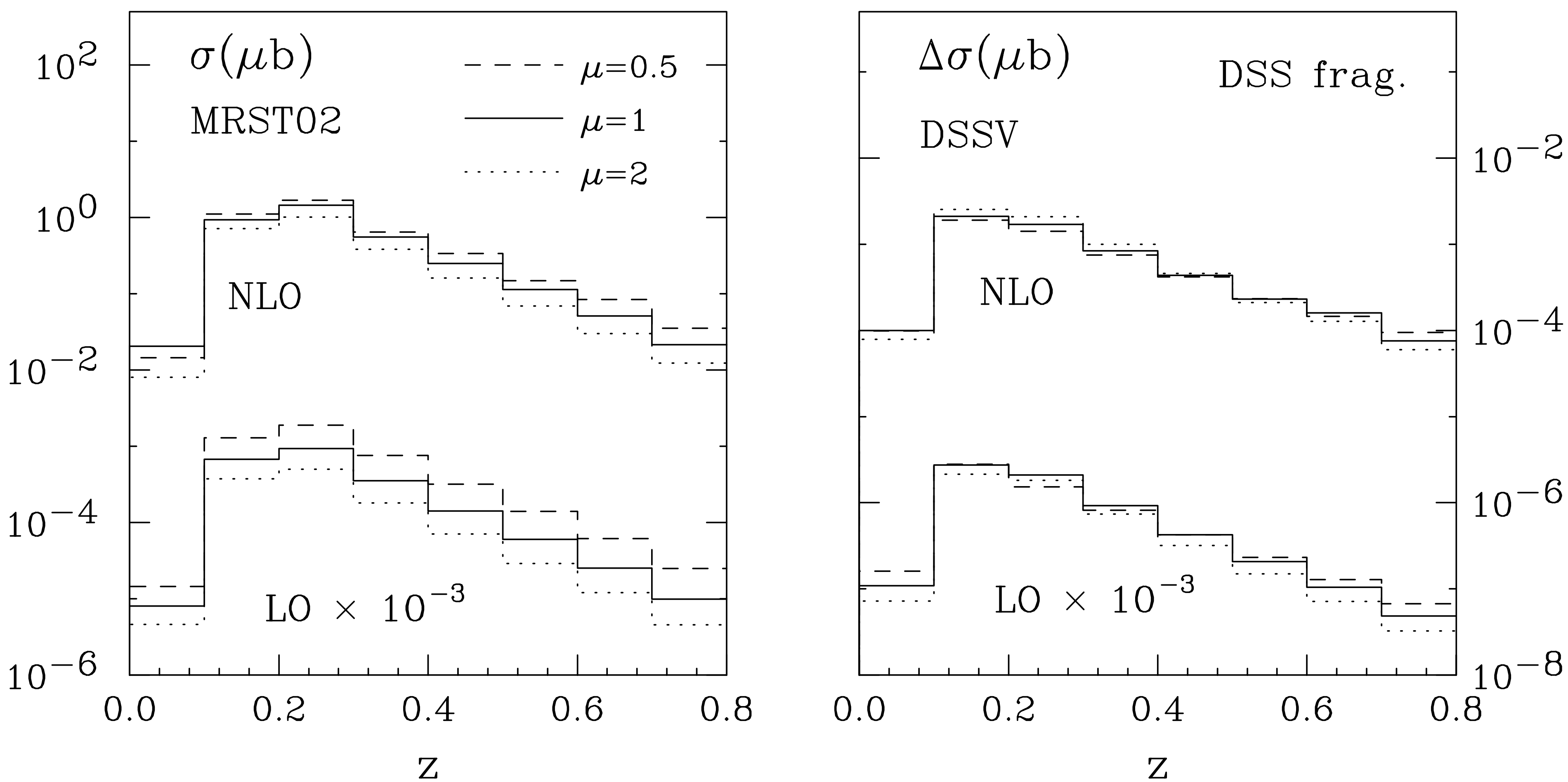
$$\mu_F = \mu_R = \left(p_T^{\pi} + p_T^{jet}\right)/2$$

- Corrections are large: > 50% for unpolarized
- Corrections are not trivial : asymmetry is reduced at NLO

NLO perturbative stability

- Considerable reduction in scale dependence at NLO

$$\mu_F = \mu_R = \mu \left(p_T^{\pi} + p_T^{jet}\right)/2$$



- Still ~20 % at NLO (80 % at LO)
- Result very stable in polarized case : measure polarized cross-section instead of asymmetry?

- Relation between 'measured' and 'real' x and z at NLO

'Measured'

$$z \equiv \frac{p_T^h}{p_T^{jet}}$$

$$x_1 \equiv \left(p_T^{jet}\exp(\eta_{jet}) + p_T^{jet}\exp(\eta_h)\right)/\sqrt{s}$$

$$x_2 \equiv \left(p_T^{jet}\exp(-\eta_{jet}) + p_T^{jet}\exp(-\eta_h)\right)/\sqrt{s}$$

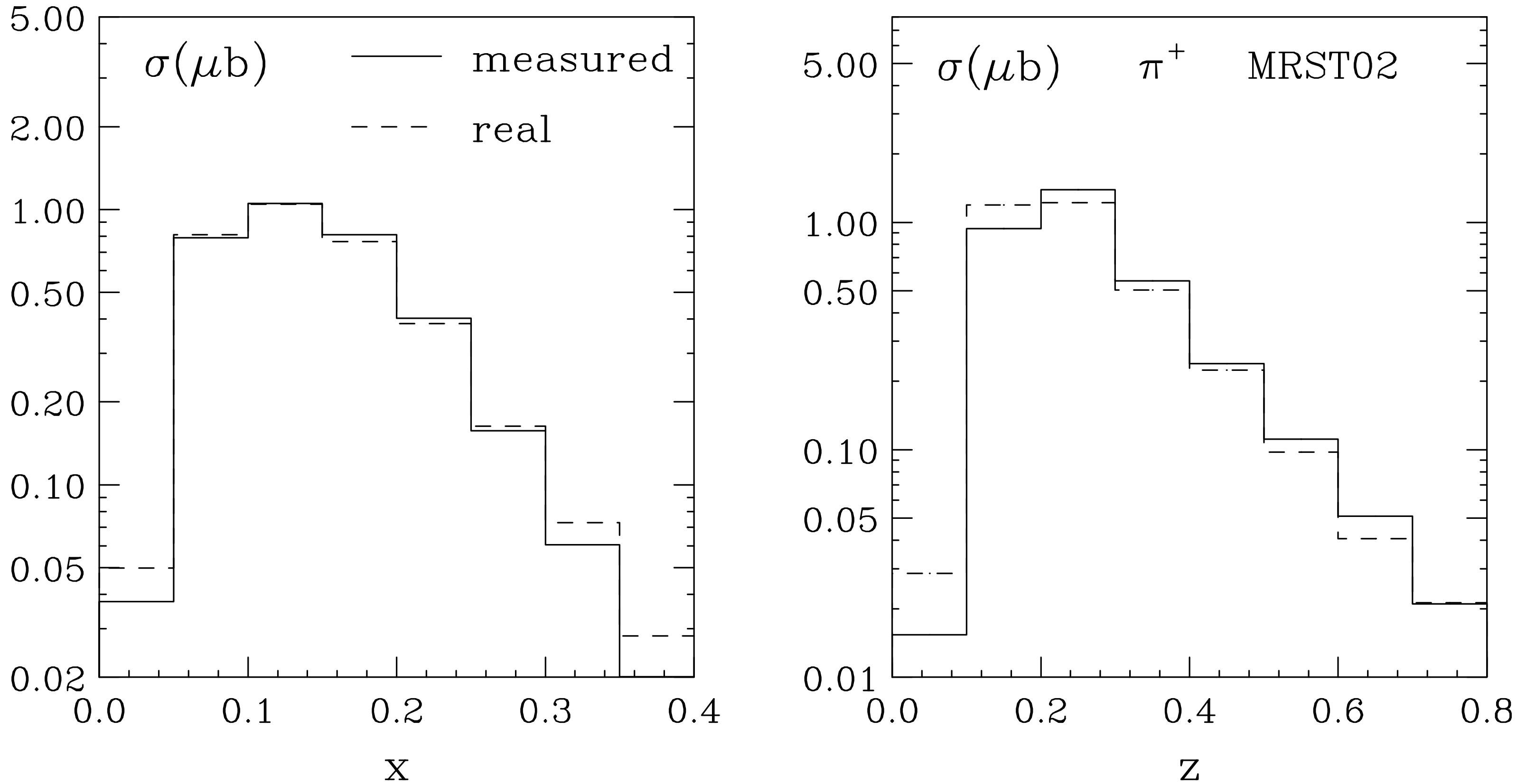
'Real'

$$f_i(x_{1,2})$$

$$D_i(z)$$

- Differential cross-sections

Symmetric in x_1 and x_2



agreement at % level

10-15% difference

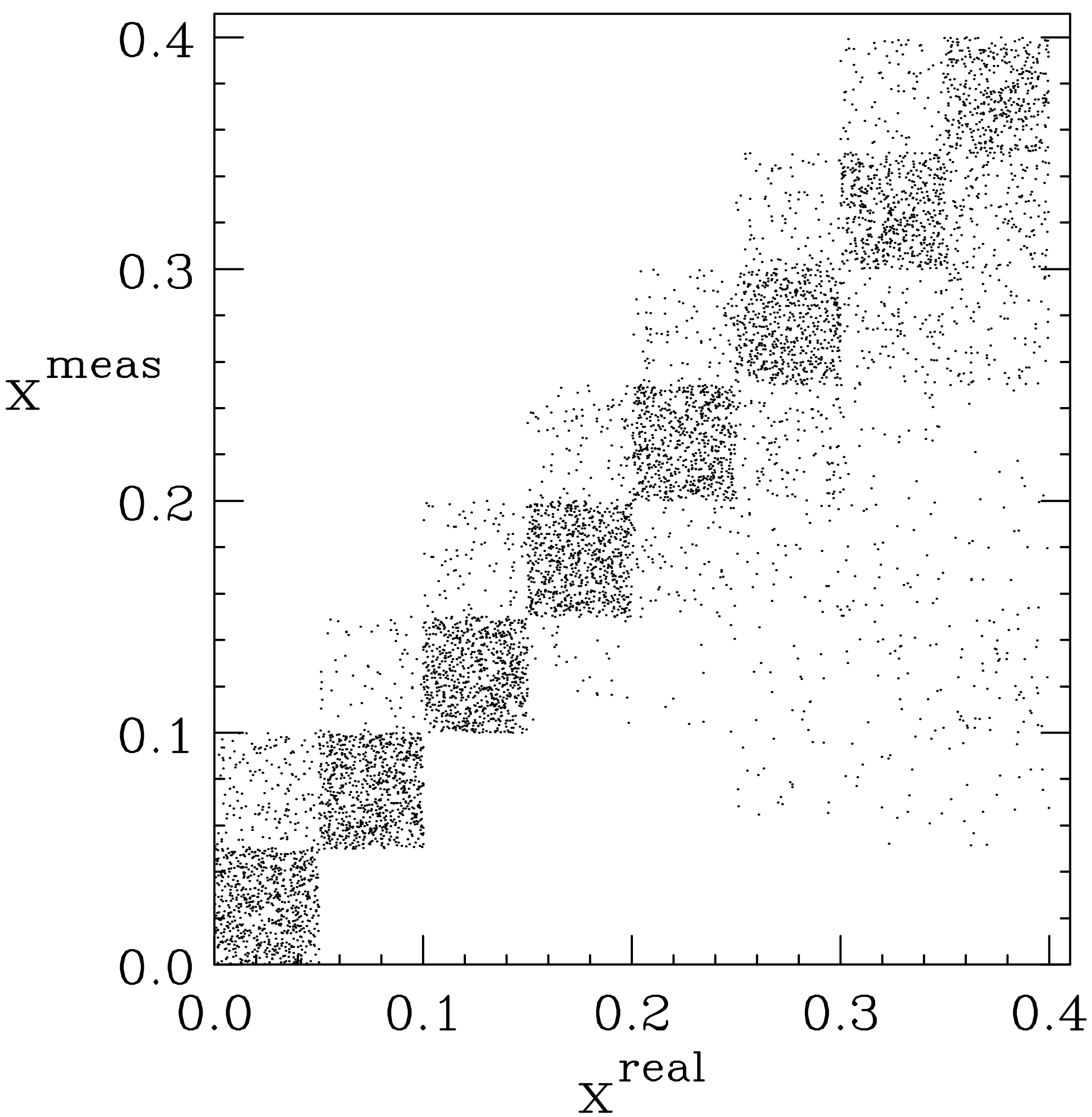
dominant range

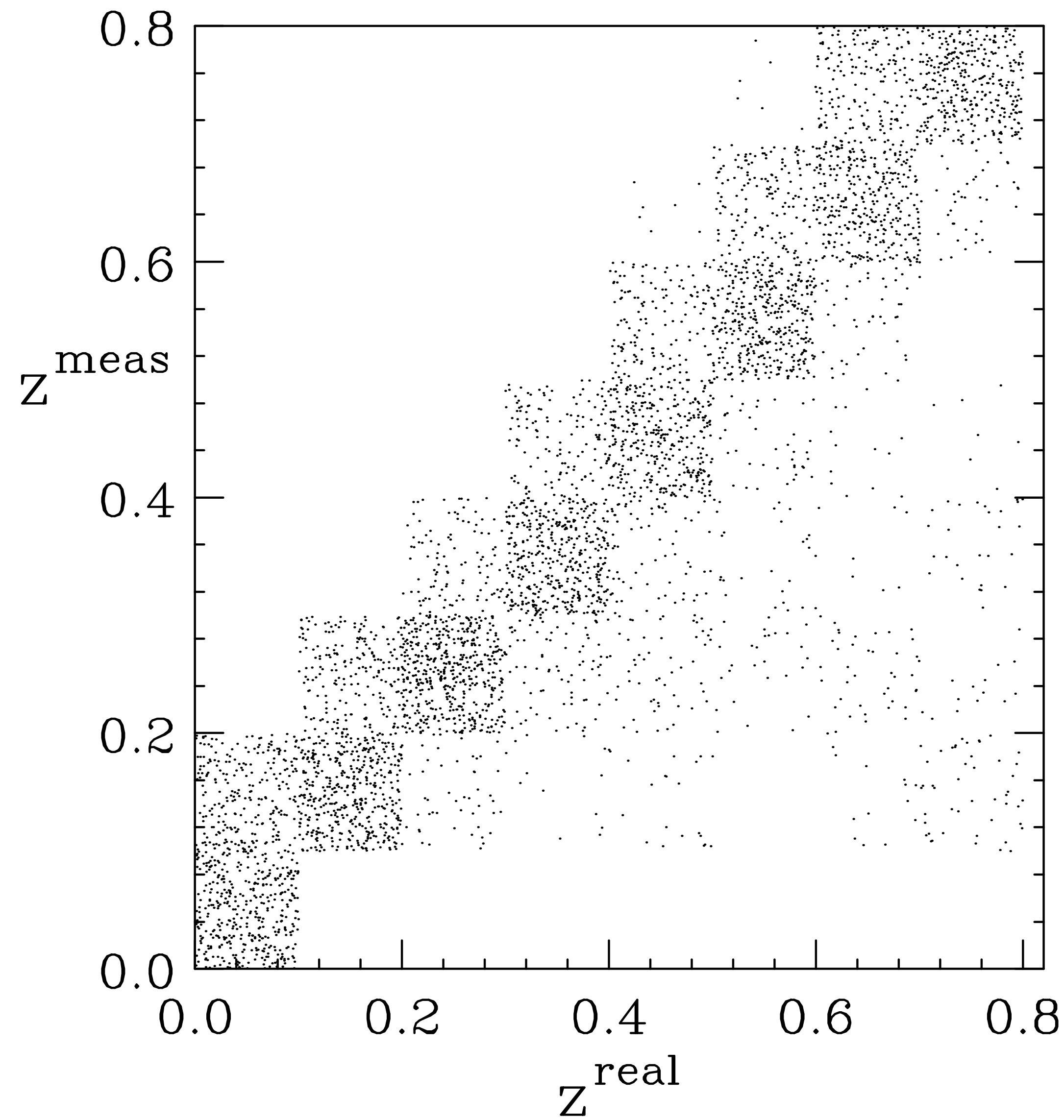
$0.05 \lesssim x \lesssim 0.3$

$0.1 \lesssim z \lesssim 0.5$

- Correlations between ‘measured’ and ‘real’ x and z

Generate ‘events’ at NLO and compare





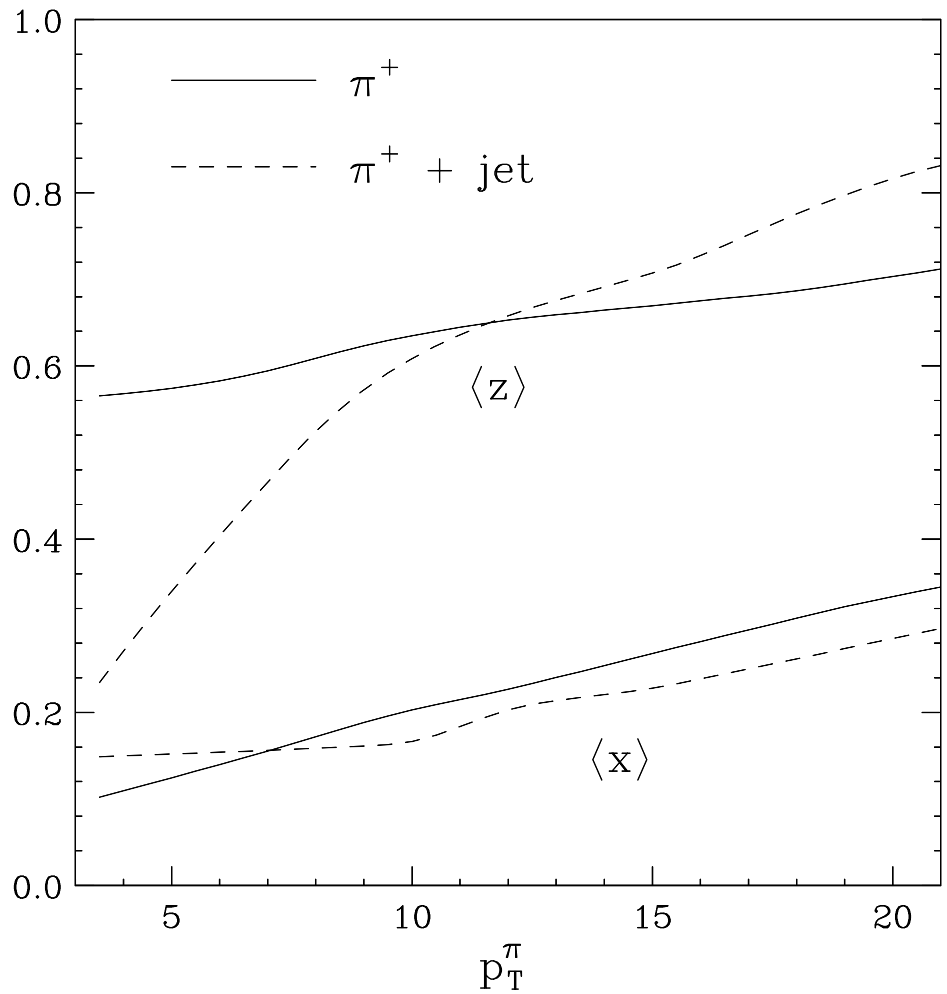
bin size 0.05 : 90 % correlation

bin size 0.1: 60 % correlation

Still use global fit at NLO (not naive parton model assumptions)
but correlation already interesting

Counting with the jet helps!

Inclusive vs 'Exclusive' average of momentum fractions x and z

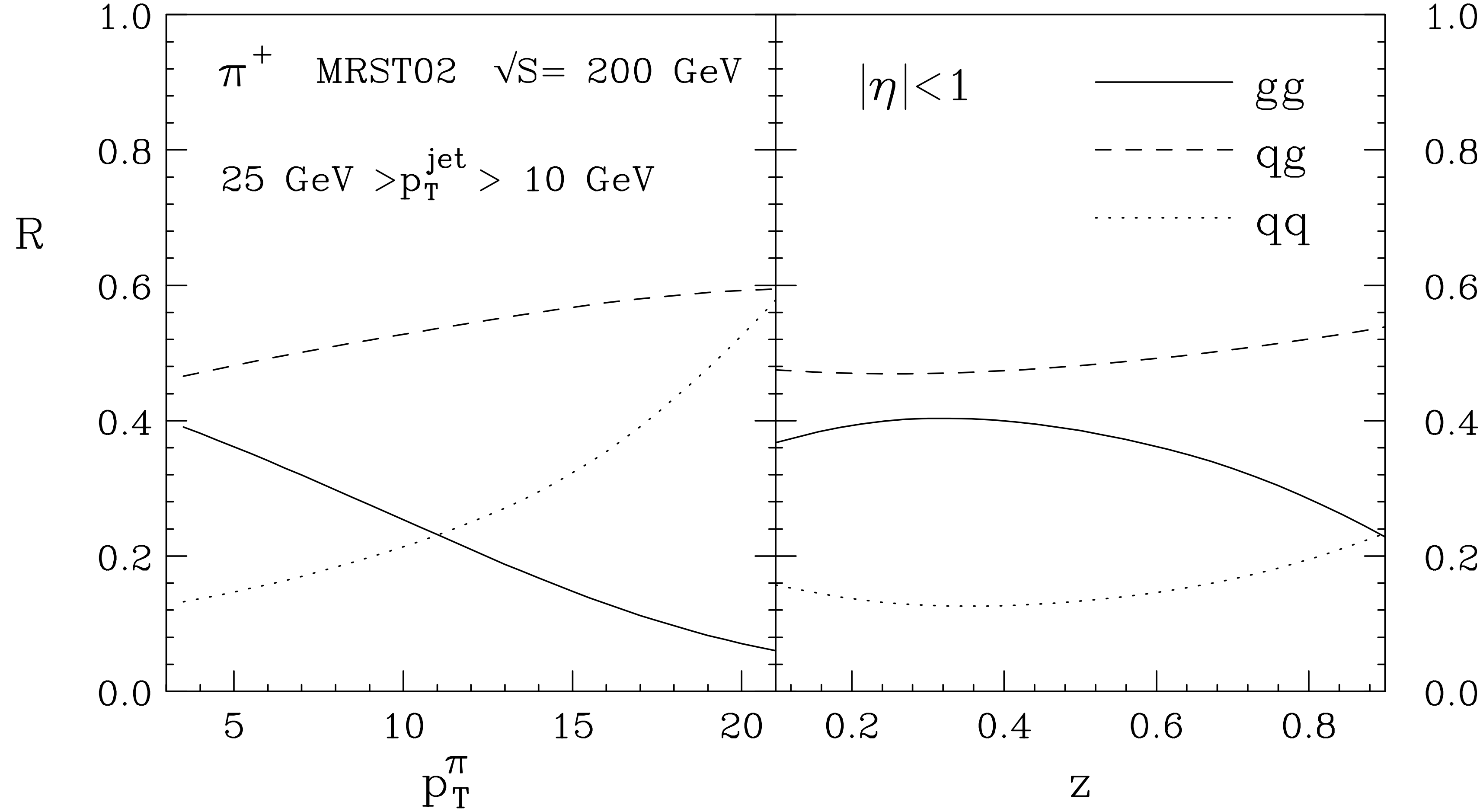


$p_T^{jet} > 10\ GeV$

Selecting momentum of pion is like selecting z

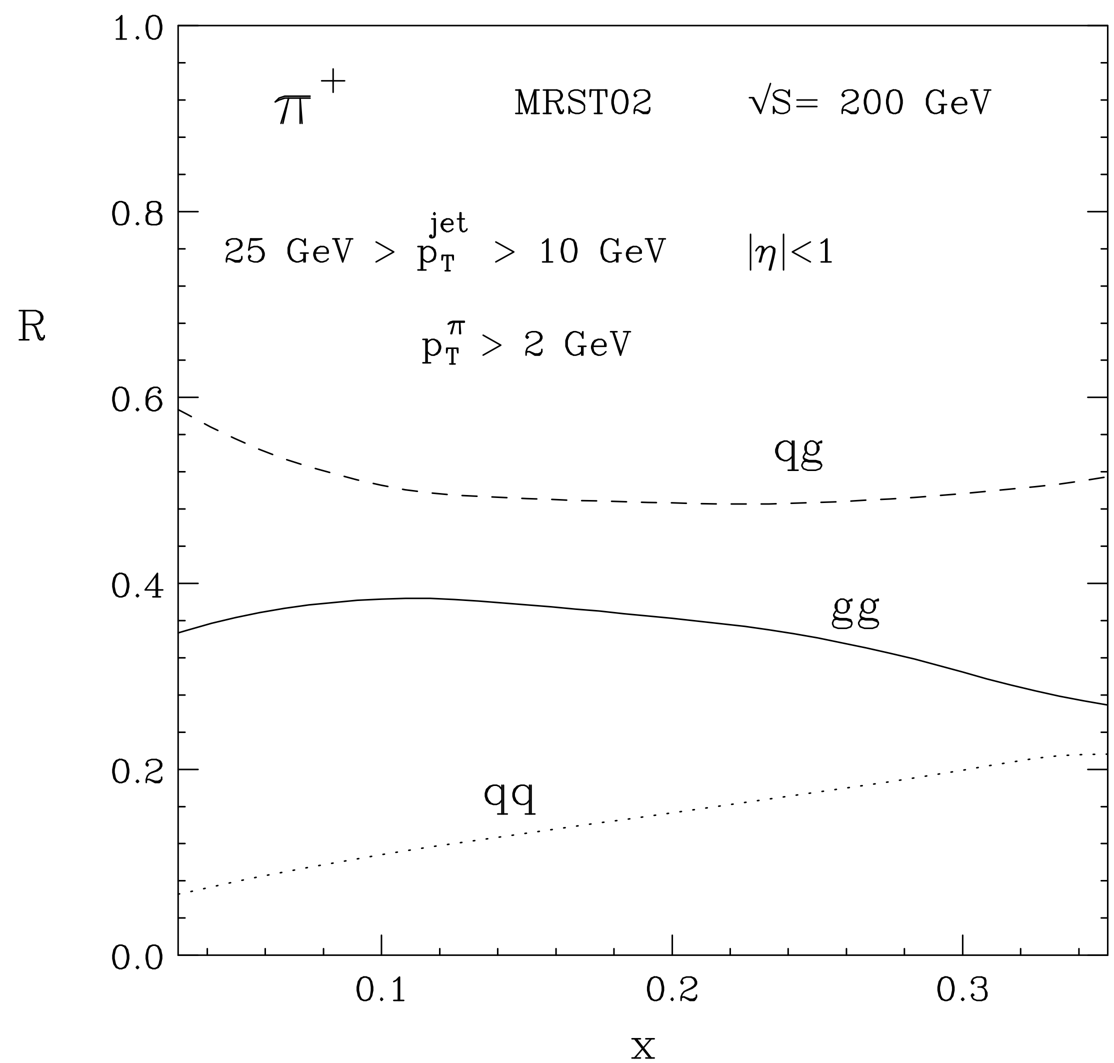
Use that possibility to enhance some partonic channel

- For inclusive pions : gg only relevant at small transverse momentum
- With pion+jet : gg sizable for a wide range of z



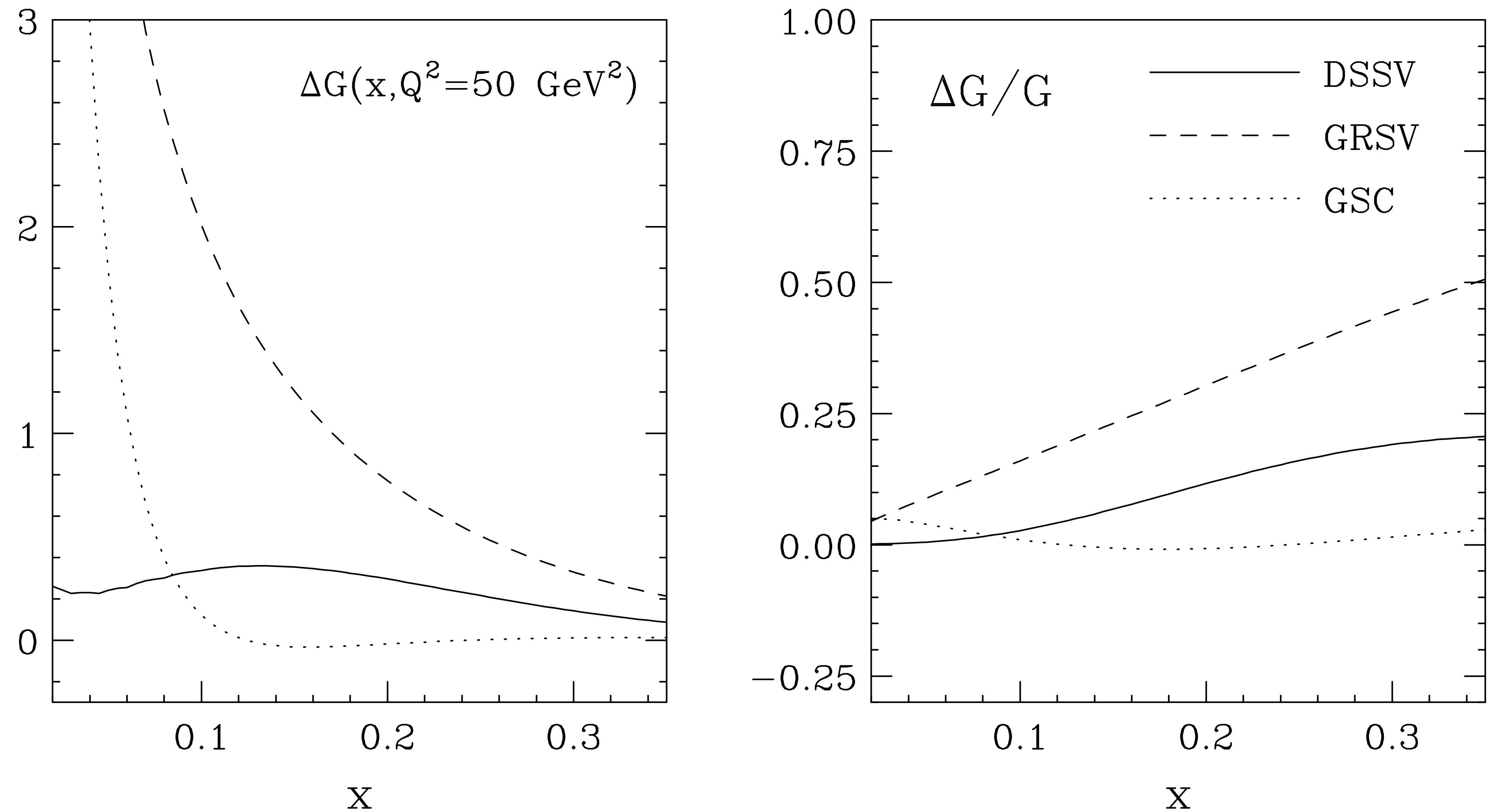
- More exclusive observable allows to enhance sensitivity on ΔG
- Sensitivity full z range ~ small transverse momentum

- Similar features in terms of momentum fraction x

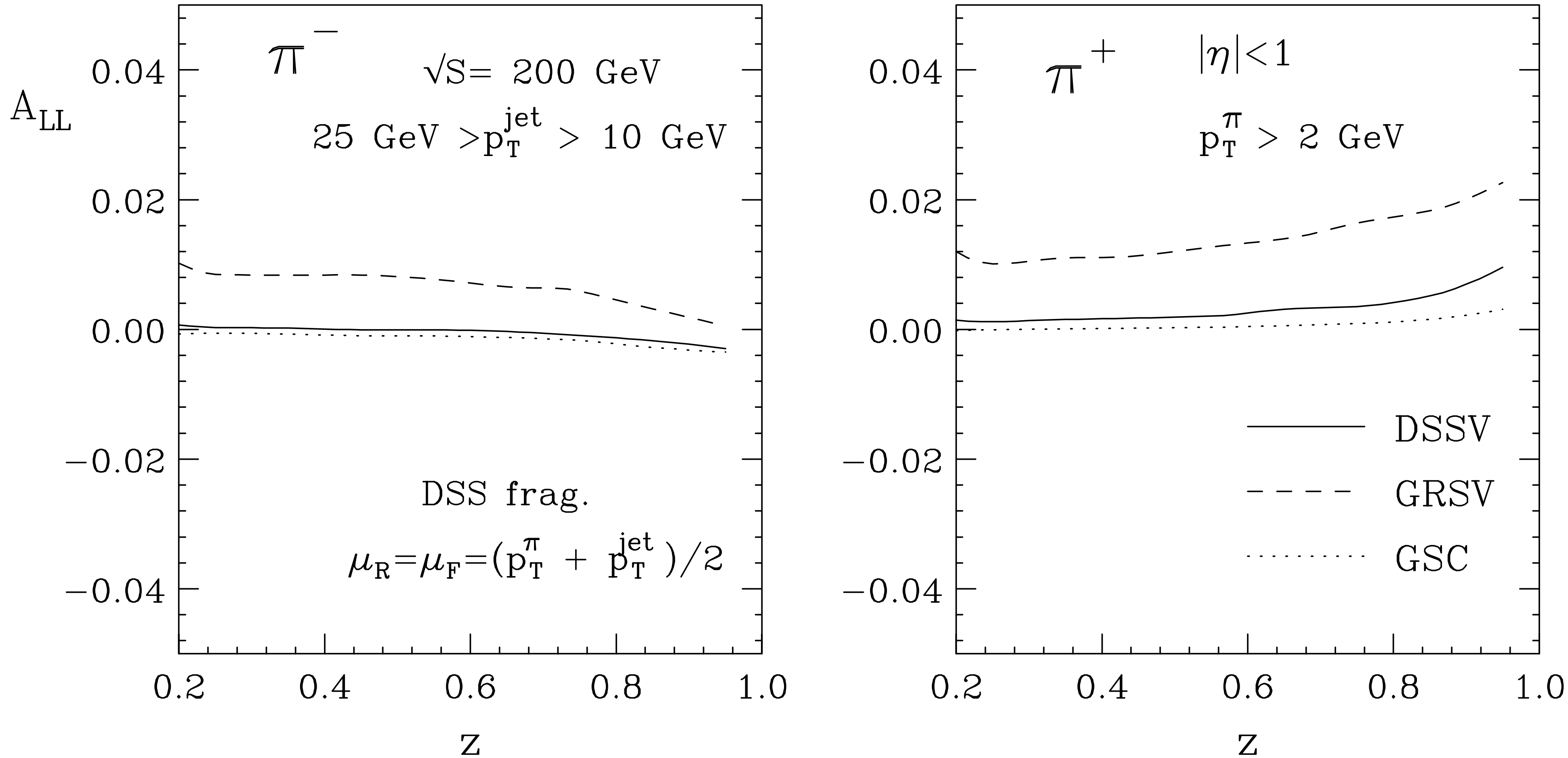


- Use 3 different sets of polarized pdfs

DSSV best fit from global analysis : small gluon polarization
GRSV(std) : larger polarization (> upper limit allowed by data)
GS(C) : small polarization at medium x but much larger at small x



- z dependence Asymmetries < 1%



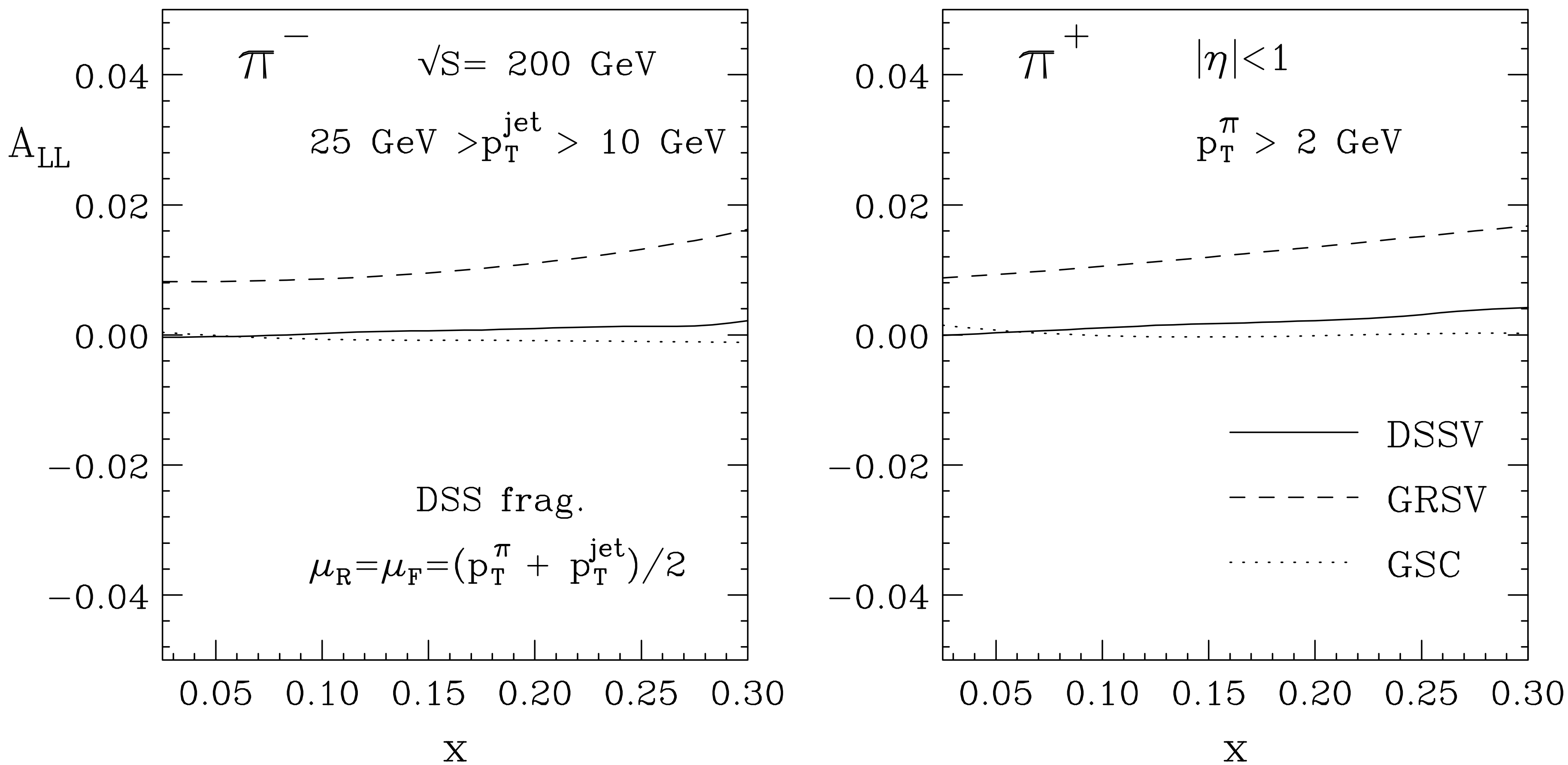
$$\Delta g\,(\Delta u\, D_u^\pi(z) + \Delta d\, D_d^\pi(z))$$

- At small z $D_q^{\pi+}(z) \sim D_q^{\pi-}(z)$ result becomes ~ charge independent
- At large z : 'favored' fragmentation dominates

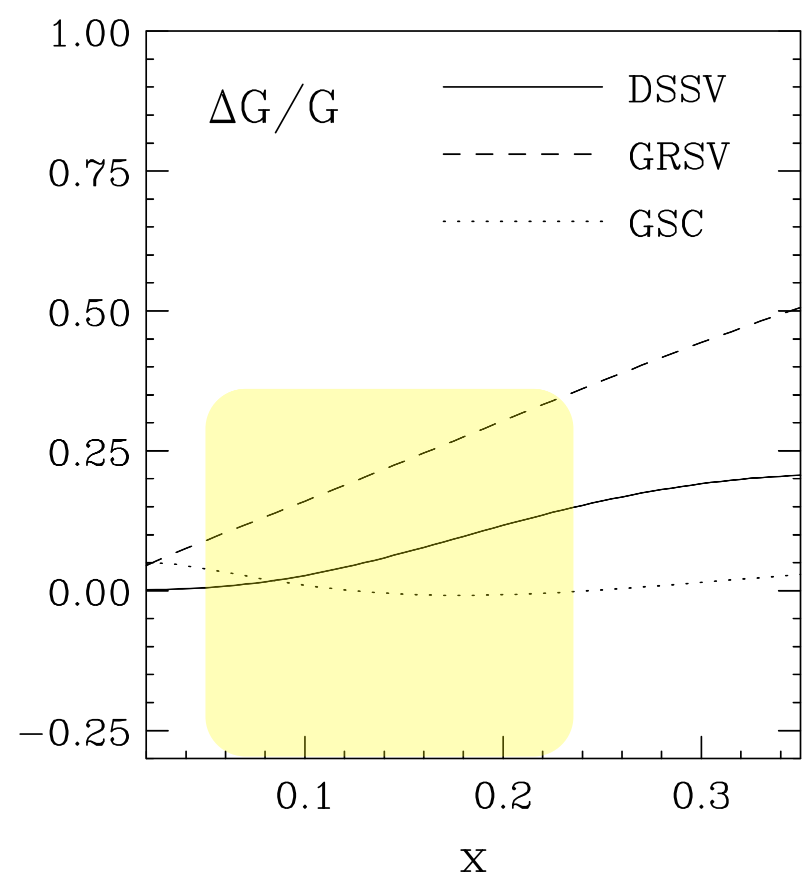
$$\pi^+ \quad \Delta g\,(\Delta u\, D_u^\pi(z) + \Delta d\, D_d^\pi(z))$$

$$\pi^- \quad \Delta g\,(\underset{+}{\Delta u}\, D_u^\pi(z) + \underset{-}{\Delta d}\, D_d^\pi(z))$$

- x dependence : sensitivity increased π^-



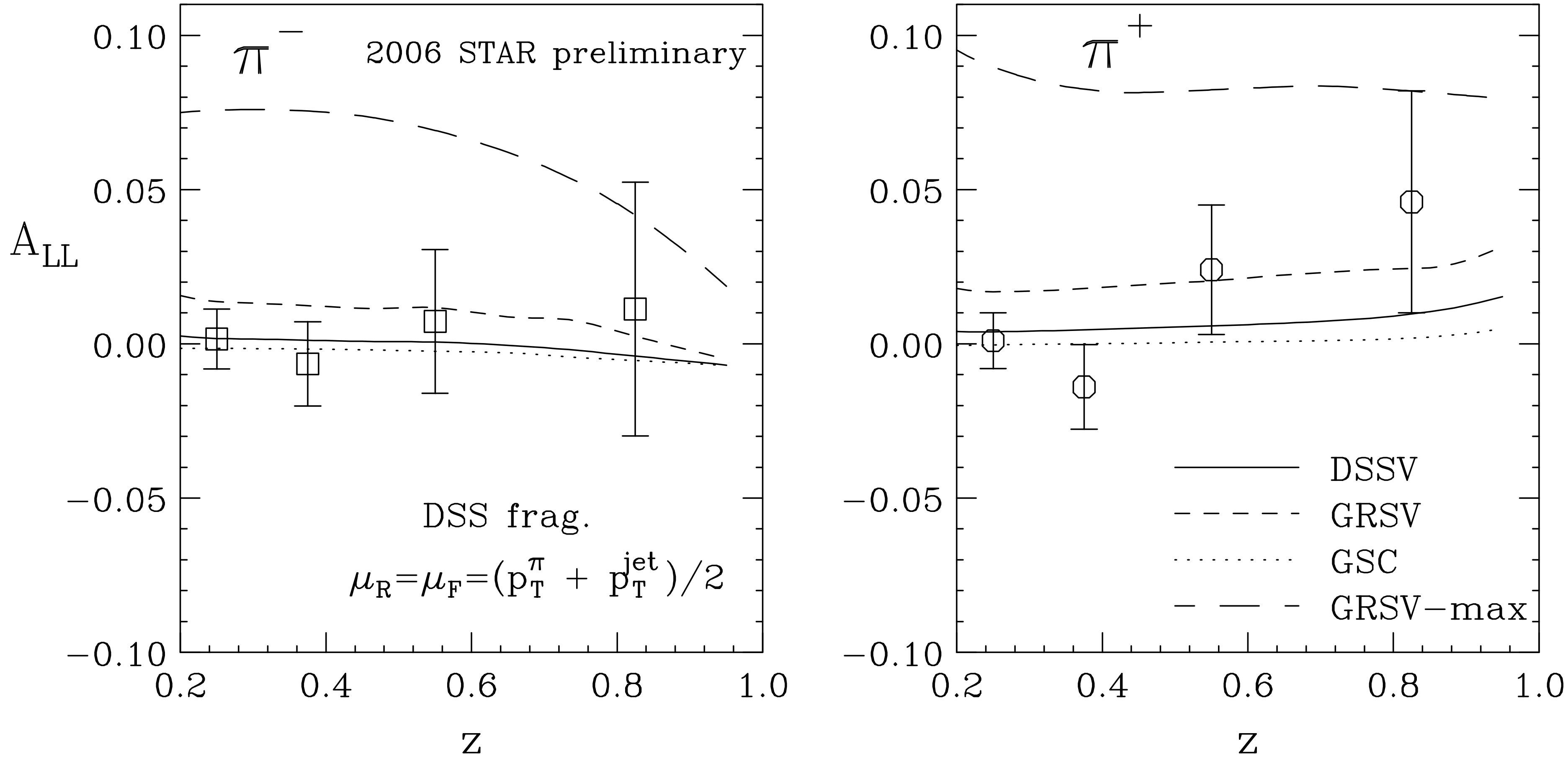
- Follows the pattern of $\Delta g/g$



- Comparison to STAR data (not corrected for trigger effects)

TH results modified according to trigger efficiency

Larger asymmetries: bias towards larger p_T



- Data consistent with small gluon polarization in range $0.05 \lesssim x \lesssim 0.3$

- Still large errors to deserve ‘global fit treatment’ : technique available

- Experimental work : analysis in terms of x

- 500 GeV : smaller x

Conclusions

- More exclusive observables allow a more detailed analysis of polarized gluon
- Pion+jet : ‘precise’ reconstruction of momentum fractions
- Sensitivity to $\Delta G \;\; \mathrm{in} \;\; 0.05 \lesssim x \lesssim 0.3$
- Preliminary data compatible with ‘very’ small gluon polarization (DSSV-like)